

Chapter 12

Summary and Conclusions

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The purpose of this project is to conduct a thorough literature review of contemporary and projected urban stormwater management practices in the U.S. and other parts of the world. Based on this review, a framework for evaluating the effectiveness of innovative stormwater management systems for the 21st century is presented. Summaries and conclusions for the individual chapters are presented below.

Chapter 2: Principles of Integrated Urban Water Management

The results of the evaluation of the nature of imperviousness in urban areas show that the quantity of urban stormwater generated per dwelling unit has increased dramatically during the 20th century due to the trend towards more automobiles which require more streets and parking, and the trend towards larger houses on larger lots. Commercial and industrial areas need much more parking per unit of office space than they did before automobiles. Modern practices dictate devoting more of the city landscape to parking than to human habitat and commercial activities.

The net result of this major shift in urban land use is low density sprawl development that generates over three times as much stormwater runoff per family than did pre-automobile land use patterns. Much of these requirements for more and wider streets and parking have been mandated in order to improve the transportation system. Ironically, unlike water infrastructure, these services are not charged directly to the users. Rather, they are subsidized by the general public including non-users.

Chapter 3: Sustainable Urban Water Management

More sustainable water systems can be achieved by promoting water conservation to reduce the amount of water that must be imported into cities. Outdoor water use is the largest source of variability in urban water use. Reuse of treated wastewater and stormwater for nonpotable uses, such as toilet flushing and irrigation, would greatly reduce urban water supply needs. Infiltration and inflow in sewers is the largest source of variability in the quantity of wastewater going to the treatment plant. I/I amounts can be reduced considerably by improved sewer design, installation, and operation and maintenance practices. Urban stormwater varies in relative importance because of climatic variability. On the average, it is of the same order of magnitude as urban wastewater but it is much more variable.

Chapter 4: Source Characterization

The relative contributions of source areas for a specific pollutant are dependent on several factors, including the characteristics of the source area and the rain energy and volume. As expected, directly connected impervious areas contribute most of the runoff

and pollutants during small rains. However, as the rain depth increases, non-paved areas can become significant.

If the number of events exceeding a water quality objective are important, then the small rain events are of most concern. Stormwater runoff typically exceeds some water quality standards for practically every rain event (especially for bacteria and some heavy metals). In the upper Midwest, the median rain depth is about six mm, while in the Southeast, the median rain depth is about twice this depth. For these small rain depths and for most urban land uses, directly connected paved areas usually contribute, most of the runoff and pollutants. However, if annual mass discharges are critical (e.g. for long-term effects) then the moderate rains are more important. Rains from about 10 to 50 mm produce most of the annual runoff volume in many regions of the U.S. Runoff from both impervious and pervious areas can be very important for these rains. The largest rains (greater than 100 mm) are relatively rare and do not contribute significant amounts of runoff pollutants during normal years, but are very important for drainage and flood control design. The specific source areas that are most important and controllable for these different conditions vary widely.

Other important source area factors affecting stormwater management concern runoff pollutant characteristics for the different areas. Particle size of particulates in the runoff greatly affect many stormwater control practices, such as detention facilities and filters. If the majority of the particles can be removed from stormwater, much of the potential problem pollutants are also removed. Unfortunately, the actual particle sizes are probably much smaller than typically assumed during the design of these facilities.

Chapter 5: Receiving Water and Other Impacts

Urban receiving water may have many beneficial uses, including:

- Stormwater conveyance (flood prevention).
- Non-contact recreation (e.g., linear parks, recreation, boating).
- Biological uses (e.g., warm water fishery, biological integrity).
- Contact recreation (e.g., swimming).
- Water supply.

With full development in an urban watershed and with no stormwater controls, it is unlikely that any of these uses can be fully obtained. With less development and with the application of stormwater controls, some uses may be possible.

There are many instances of receiving water problems associated with urban stormwater reported in the literature. Receiving water problems associated with urban stormwater are highly varied. In watersheds that are lightly developed and have relatively large receiving waters, the impacts are not as obvious as in heavily developed watersheds in more arid areas.

Chapter 6: Collection Systems

By applying new technology and revisiting traditional urban water problems with a fresh outlook, advances are being made in a wide variety of sewer related areas. Integrated storm/sanitary systems may emerge in the 21st century, that is, combined sewers may be strategically designed into new urban development. Storm runoff will be reduced by source control and infiltration BMPs and the residual of small events will be transported to the WWTP. Large events will be throttled out of the integrated system, before mixing with sanitary waste, and discharged to receiving waters. This new system will have the best of both combined systems and separate systems. The advantage of the combined system has been treatment of small runoff producing events, including snowmelt. However, the disadvantage has always been the discharge of raw sewage to receiving waters during large events. With the advantage of control technology, as the sewers and/or the WWTP reach capacity, the stormwater could be stored and/or diverted directly to receiving waters without mixing with sanitary and industrial wastes. Future systems will have a high degree of built in control.

Outlying from the new urban centers, suburban type development still exists. While less dense than the city, new suburban development will contain some of the mixed land uses found in the urban center. The collection system serving this area will be far different from the city, however, because the NPS pollution is not so severe as to warrant full treatment at the WWTP. BMPs and source control innovations will reduce stormwater impacts on the receiving water. Regional detention will be used for flood control and water quality enhancement. Sanitary wastes will be transported via pressure sewers to collector gravity lines at the city's border. The use of pressure sewers will reduce suburban I/I to near zero. In addition, the new sanitary low pressure sewers will be very easy to monitor because the age-old problem of open channel flow estimation will be avoided by using pressure lines. This provides added certainty in the flow estimation and facilitates control. Technology borrowed from the water distribution field will achieve a great level of system reliability and control. In fact, the sewer will now mirror the water distribution network, essentially providing the inverse service.

Chapter 7: Assessments of Stormwater Best Management Practices Technology

Much of this chapter's discussion is based on a plethora of information that is supported by a number of local field investigations designed to test a given BMP's effectiveness at the specific site. Still needed is a national approach, similar to NURP, that would systematize the results of a large number of investigations into a coherent, well controlled program to learn about various BMP functions, physical mechanisms, biochemistry, and design parameters. Also needed is a better measure of effectiveness. The current measure in terms of percent removal has limited value.

Another need is improvement in the design robustness for various BMPs. Until that is done, expecting a specific performance from any given BMP is unrealistic. Design robustness will improve as knowledge is gained on selecting, sizing and designing each type of BMP. Urban stormwater management also has to consider the safety and welfare of the citizens living in the urban areas. Issues of efficient site drainage, control

of nuisances caused by inadequate drainage, the hazards posed by large storm events and the floods they create, and costs and benefits received for the expenditure of public dollars, have to be considered. As a result, sound stormwater management has to address not only mitigating the runoff impacts of urbanization, but also the public and community needs.

Chapter 8: Stormwater Storage-Treatment-Reuse Systems

In many parts of the country, particularly humid areas, enough stormwater can be collected to satisfy average irrigation demands. If driveway areas are eliminated due to possible problems with water quality and ease of collection, the result will be a larger tank size, however, irrigation demand may still be satisfied in a majority of cases. In arid areas, particularly those with high evapotranspiration requirements, stormwater reuse may not be justified by itself. In these cases, combining storage with treated graywater may be an option worth considering. An extrapolation of this work to urban/suburban areas of the U.S. is needed.

Chapter 9: Urban Stormwater and Watershed Management: Analysis Case Study

The results of examining the behavior of Boulder Creek in Boulder, CO. each hour of calendar year 1992 provide dramatic testimony to the influence of human activities on this stream. Boulder Creek is typical of streams in urban areas because of the intense level of activities associated with manipulating water resources as part of agricultural, industrial, mining, urban and/or other interests. The following conclusions, many of which can be extrapolated elsewhere, are drawn from this analysis:

1. Given the wide variability in flows, even from hour to hour, trying to find a single "design event" to analyze the impact of urban runoff, or any other single term in the water budget, is not reasonable.
2. A continuous water budget with a small time step (i.e., hourly) is essential in order to capture the reality of stream dynamics.
3. A process oriented approach is needed to accurately characterize what is happening in complex urban stream systems. The Boulder Creek system has evolved over the past 140 years and is a complex combination of facilities and processes such as reservoirs, canals, hydropower generation, imports, exports, and instream flow releases.
4. The wide variety of stakeholders associated with Boulder Creek continue to adapt the stream system and its management in light of changing attitudes and values. The Boulder Greenways Program implemented during the past decade is a dramatic example of these changes as is the City's recently enacted instream flow improvement program.

5. Population and land use management via the open space program have had a major beneficial impact on Boulder Creek. Thus, an integrated appraisal of land and water management is essential.
6. A key point brought out by the risk analysis is the importance of including the covariance among concentration and flow and among flows. All of these covariances help reduce the impact of stormwater runoff.
7. Ultimately, real-time water management will exist in urban areas. Thus, cities will be able to deterministically manage the concentrations and the flows entering the receiving waters throughout the year.

Chapter 10: Cost Analysis and Financing of Urban Water Infrastructure

The variability in the cost per dwelling unit for urban water supply is mainly due to the amount of lawn to be watered and the need for irrigation water. In more arid parts of the U.S., most of the water entering cities is used for lawn watering. The major factor affecting the variability in wastewater treatment costs is the amount of infiltration and inflow. The required lengths of pipe for water supply and wastewater systems can be approximated based on dwelling unit density and ratios of the off-site pipe lengths to the on-site pipe lengths. Piping lengths per dwelling unit increase if central systems are used because of the longer collection system distances.

The costs of stormwater systems per dwelling unit vary widely as a function of the impervious area per dwelling unit and the precipitation in the area. Urban sprawl has greatly increased the cost per dwelling unit for stormwater because of the large increase in impervious area per dwelling unit.

If detention systems are needed, then storage costs per dwelling unit range from about \$850 for 10 DU/acre to over \$3,000 per DU for 2 DU/acre. If stormwater receives primary treatment, then the cost per DU range from \$129 to \$1,829 as a function of runoff and dwelling unit density. For wetter, higher density areas, stormwater piping costs per dwelling unit range from \$1,100 to \$15,400 depending upon density and population size. The development of neighborhood stormwater management systems with potential for reusing some of this water for non-potable purposes should be explored.

The main financing methods for urban stormwater systems are tax funded systems, service charge funded systems, exactions and impact fee funded systems, and special assessment districts. A variety of stormwater management financing systems are available that enable a local community to manage the traditional flooding and drainage problem, and also address issues of stormwater quality.

Chapter 11: Institutional Arrangements

Stormwater management institutions can incorporate existing stormwater models or a combination of these models. The organization should be locally based with adequate

legal authority to create and enforce stormwater criteria and regulations. Stormwater issues should be tackled on a limited geographic scale, preferably at the subwatershed level.

The stormwater utility approach is probably the most reliable method for ensuring funds dedicated to stormwater management. Although the future of privatization in the stormwater arena is not clear, market-based incentives such as pollutant “trading” in a watershed will clearly become more popular. Watershed-based organizations face a number of hurdles, however their role in educating the public regarding stormwater issues and involving the public in decision making could be significant. States could assist by performing more than a permitting role. Possible activities include providing guidance to and enhancing regional cooperative efforts.

The stormwater management organization will be faced with challenges such as retrofitting existing stormwater quantity structures to meet stormwater quality needs, developing guidance for riparian corridor preservation, meeting legal challenges on land use regulations, and monitoring and maintenance of stormwater structural and nonstructural BMPs. The ability to rapidly share stormwater-related information through the use of technology, such as the Internet and GIS, should help to facilitate progress in the stormwater arena.